ALICE

SM and QCD results from ALICE

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On behalf of ALICE collaboration

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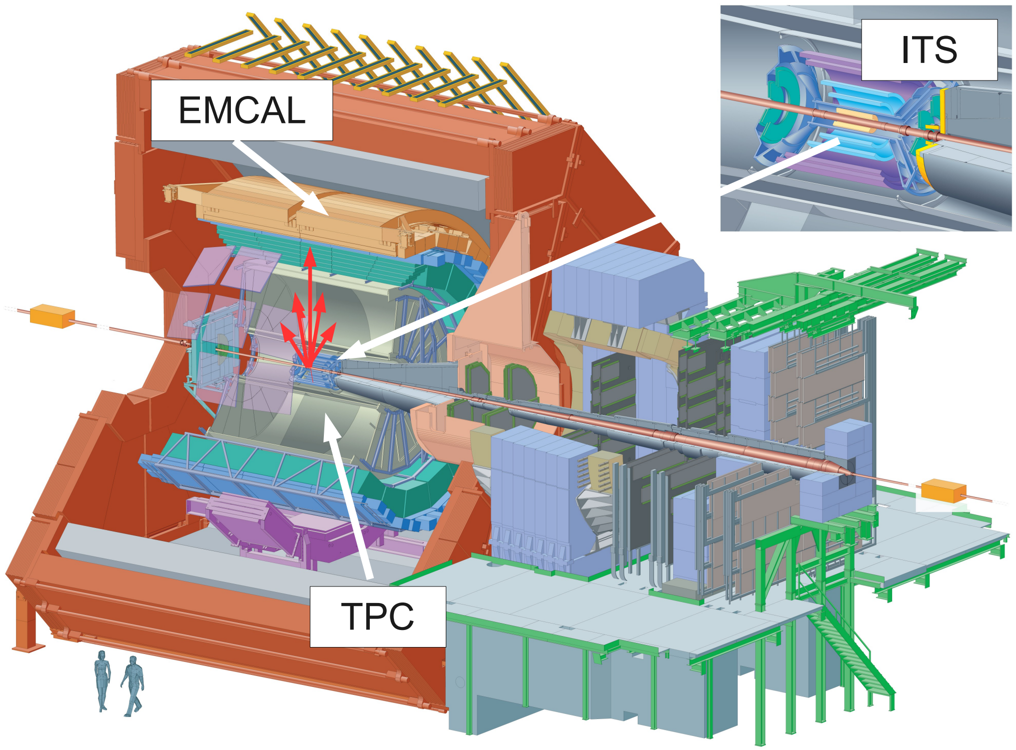
QCD studies with ALICE

- ALICE QCD studies cover a wide range of observables in pp, p-Pb, Pb-Pb collisions
- Particle identification capability allows ALICE to measure systematically spectra of many hadronic states
- In this talk, we demonstrate ALICE potential on a few results:
  - Jet production
  - Light flavour charged particle production
  - Neutral meson production
  - Heavy flavour production
  - Electroweak boson production

Jets in ALICE



ALICE performs jet studies in pp collisions to test pQCD NLO calculations.

Measured jet spectra in pp are important reference for heavy-ions

There is no unambiguous jet definition

Algorithms must be infra-red and collinear safe: adding a soft or collinear particle should not change the set of hard jets

Input for jet finder:

- Charged tracks (ITS+TPC): $|\eta|<0.9$, $0<\varphi<2\pi$, $p_T>150$ MeV/c
- Energy deposited in EMCAL: $|\eta|<0.7$, $1.4<\varphi<\pi$, E>300 MeV/c
- Corrected for charged particles matching shower in EMCAL

Inclusive jets in pp at √s=2.76 TeV

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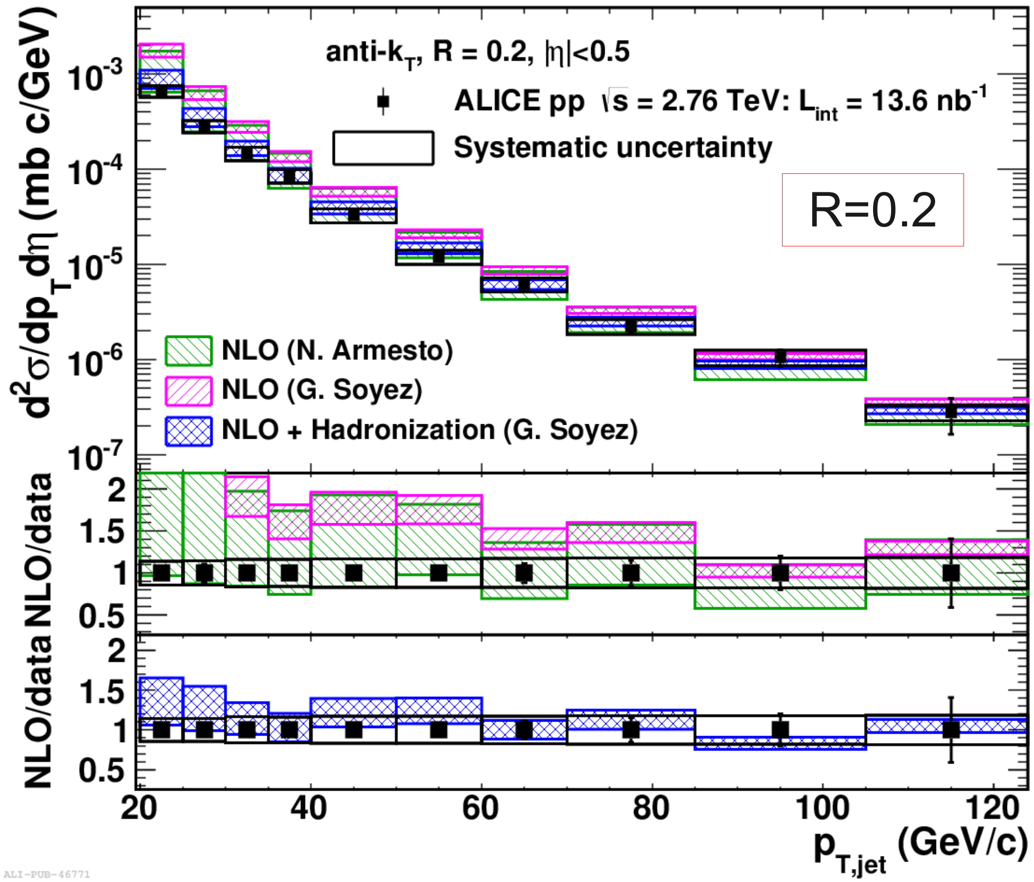
PLB 722, 262, 2013



- Hadronization is needed to describe jets.
- NLO pQCD describes jet cross section well over the whole p_T range at **R=0.2**
- This result is an important reference spectrum for jet quenching in Pb-Pb collisions

Inclusive jets in pp at √s=2.76 TeV

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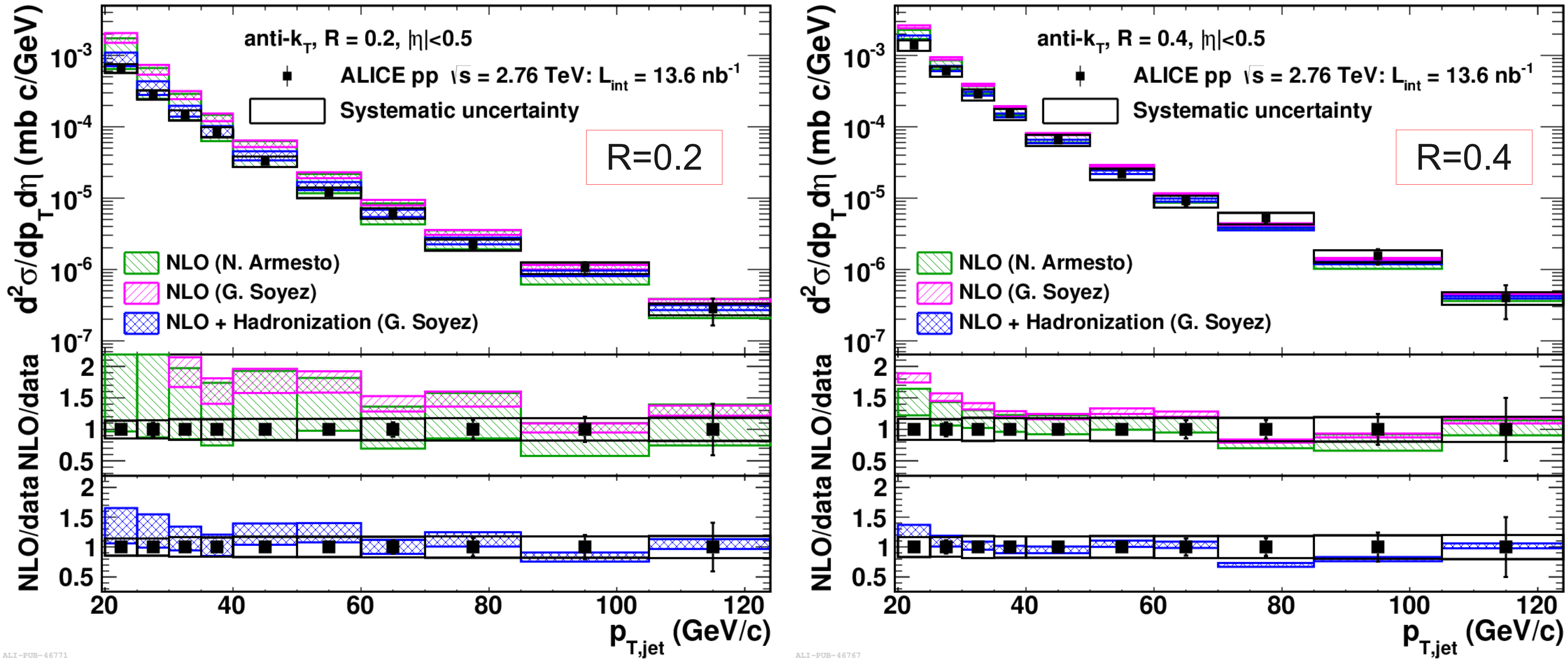
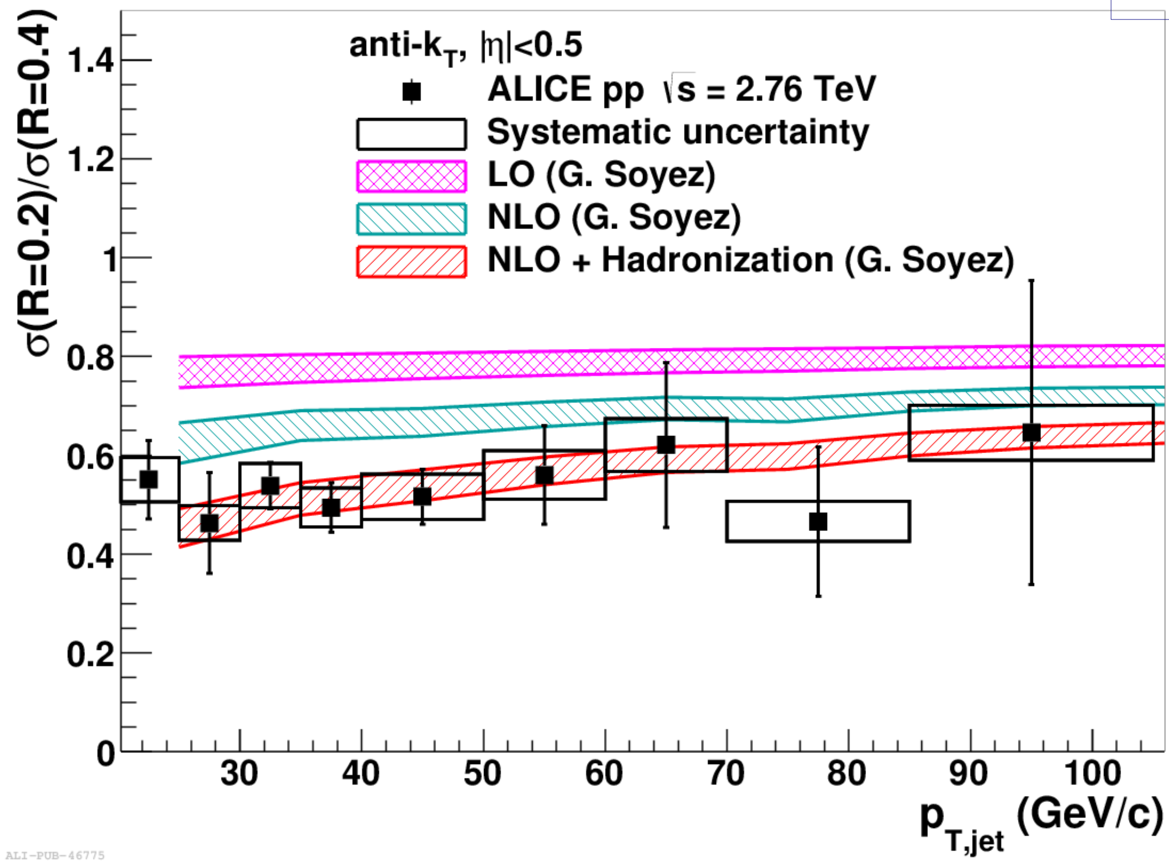
PLB 722, 262, 2013



- Hadronization is needed to describe jets.
- NLO pQCD describes jet cross section well over the whole p_T range at **R=0.2** and **R=0.4**
- This result is an important reference spectrum for jet quenching in Pb-Pb collisions

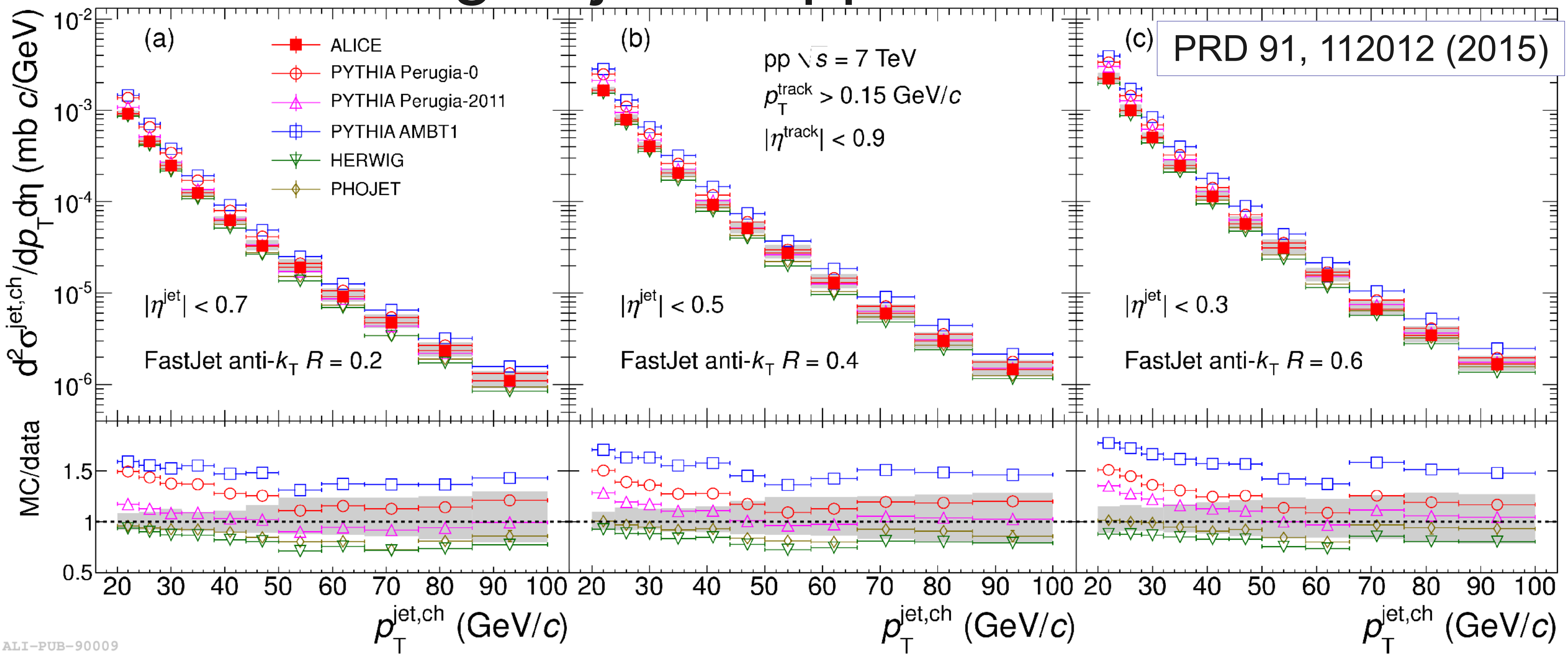
Jets vs cone radius

PLB 722, 262, 2013



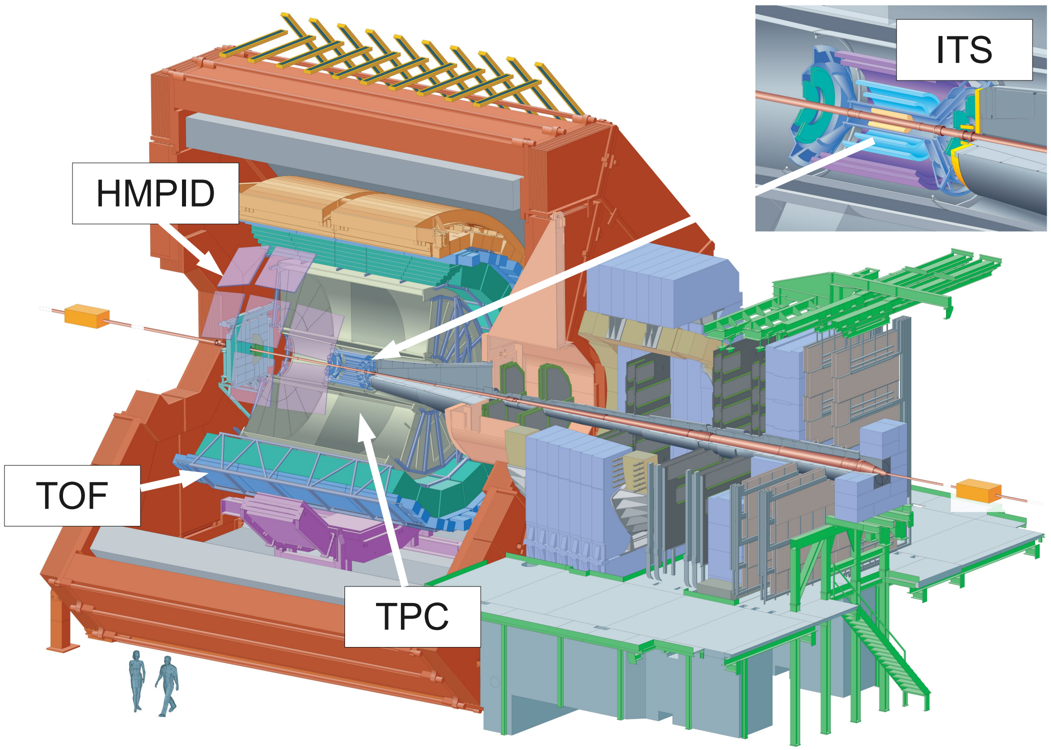
Description of the ratio of inclusive differential jet cross sections for R = 0.2 and R = 0.4 requires hadronization

Charged jets in pp at √s=7 TeV

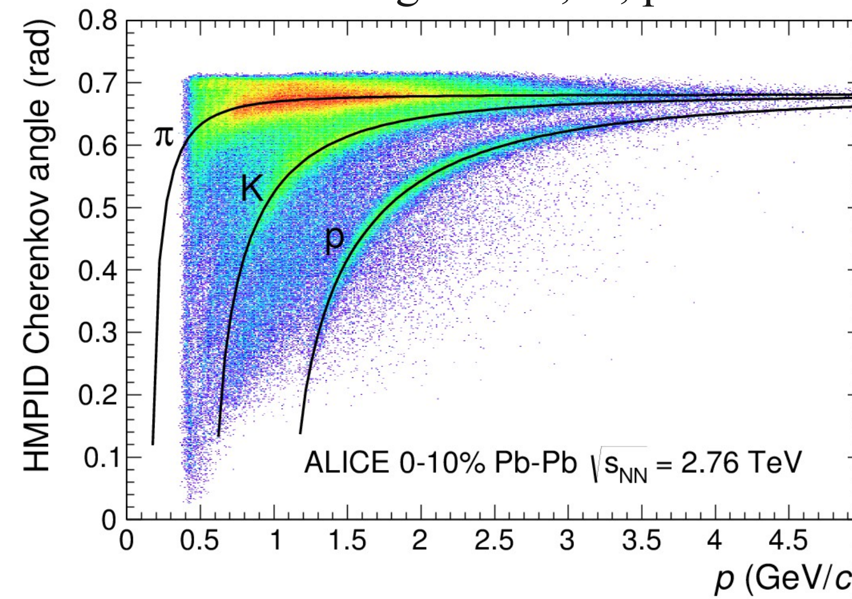


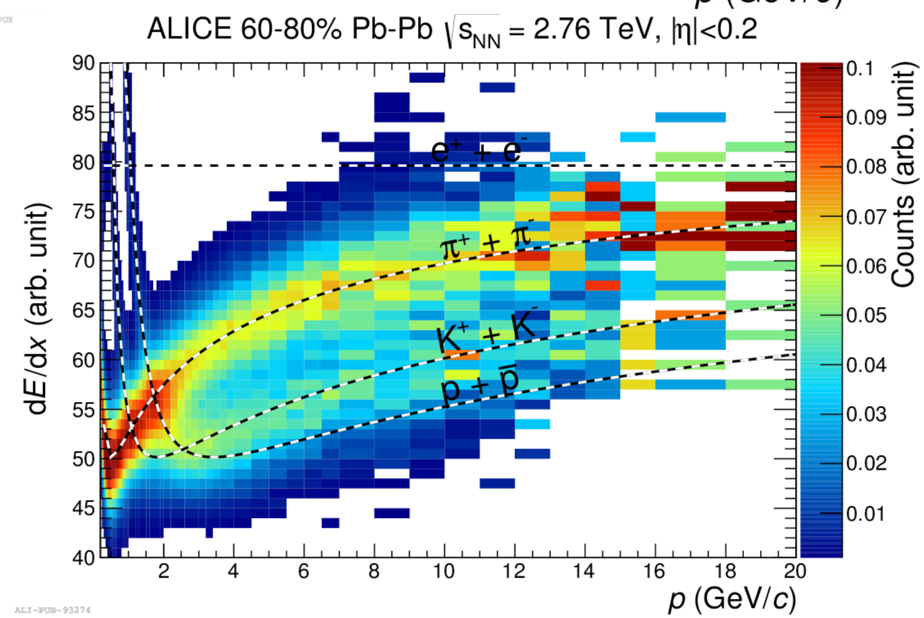
- No correction for missing neutral energy
- None of the used models could explain the charged jet production cross sections in the entire measured p_T range. Discrepancy increases with R
- The same models which could not explain the jet production cross sections, well reproduce the jet shapes (radial momentum density distribution) and fragmentation function:
  - Radial momentum density distribution is better described by PYTHIA, tune Perugia 2011
  - Fragmentation distribution is better in HERWIG

Light flavours



Cherenkov angle for π, K, p in HMPID



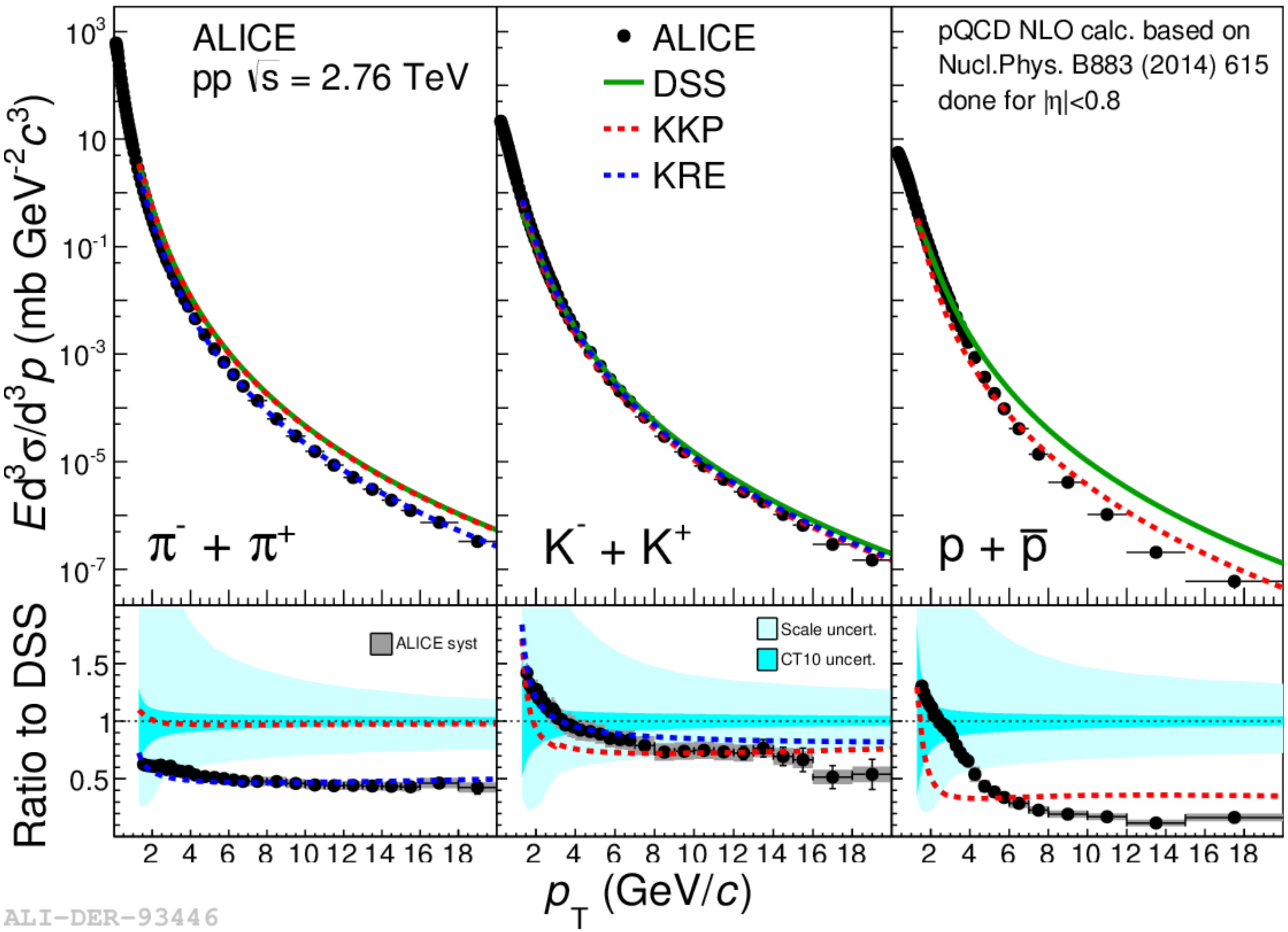


Ionization loss dE/dx in TPC

ALICE is equipped with unprecedented set of PID detectors deploying almost all experimental methods of particle identification

See talks F.Noferini, *PID at ALICE*
J.Klein, *The ALICE TRD*

Charged hadrons: comparison with pQCD



PLB 736 (2014) 196-207

NLO calculation: choise of the best fragmentation functions

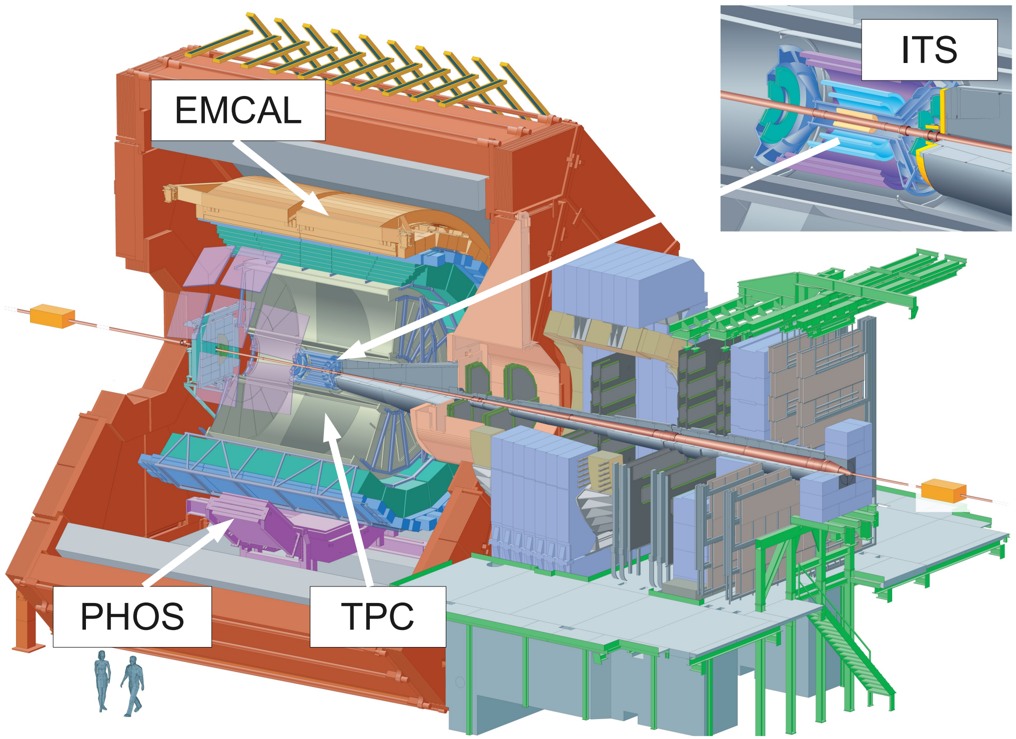
DSS: de Florian, Sassot, and Stratmann, PRD 75 (2007) 114010 and PRD 76 (2007) 074033.

KKP: Kniehl, Kramer, and Potter, NPB 582 (2000) 514.

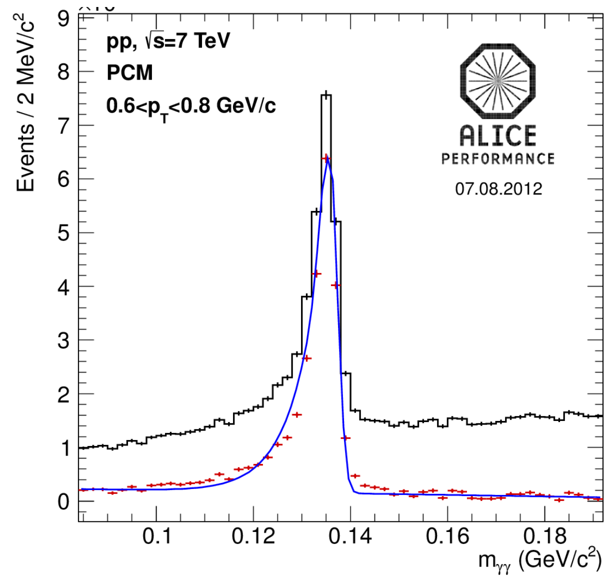
KRE: Kretzer, PRD 62 (2000) 054001.

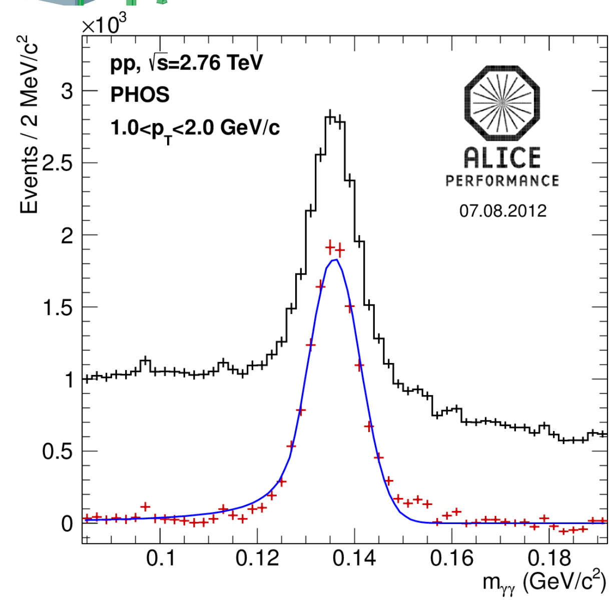
- KRE FF describes best the charged pions and kaons. The same FF described earlier charged particle spectra (d'Enterria et al., Nucl.Phys.B883).
- Kaon spectra are better described by all sets of FFs: DSS, KKP, KRE.
- Protons have largest variations from FF choice.
- The pQCD understanding of particle spectra are also important for the relative importance of quark and gluon jets in energy loss calculations.

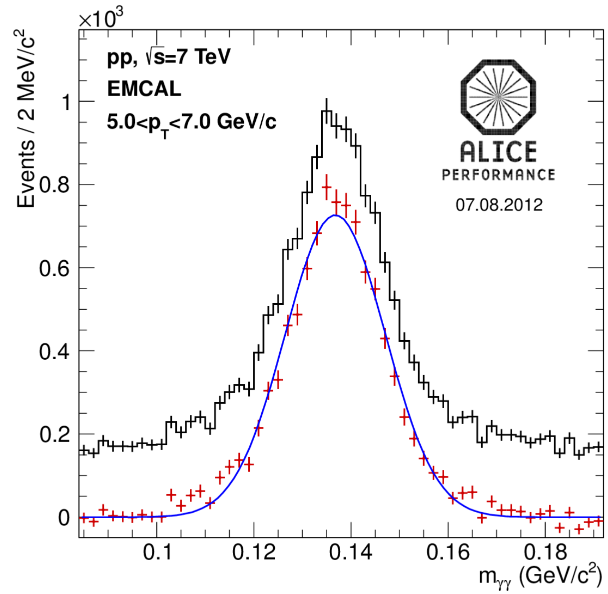
Light neutral mesons



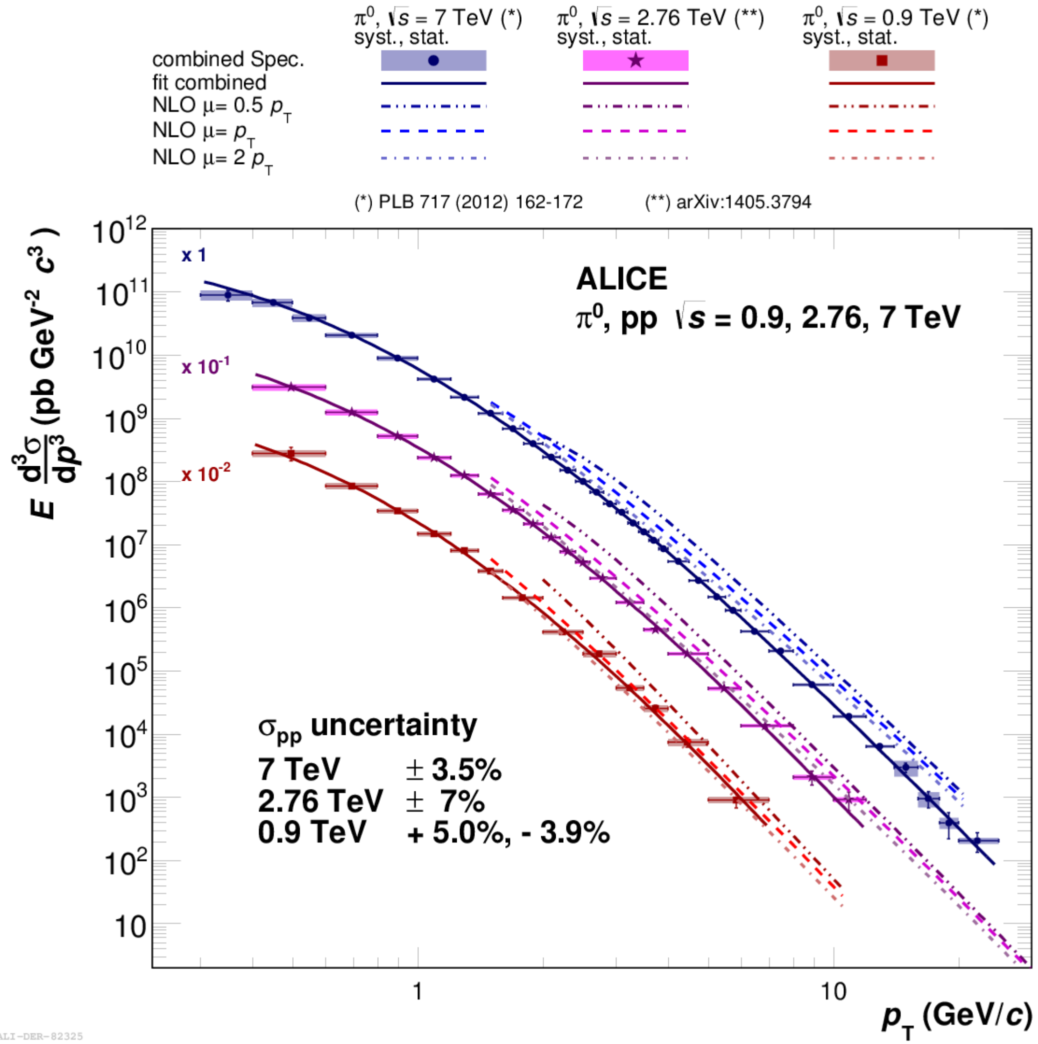
Neutral mesons can be detected via photonic decay channels in two electromagnetic calorimeters, PHOS and EMCAL, and in tracking system via photon conversion

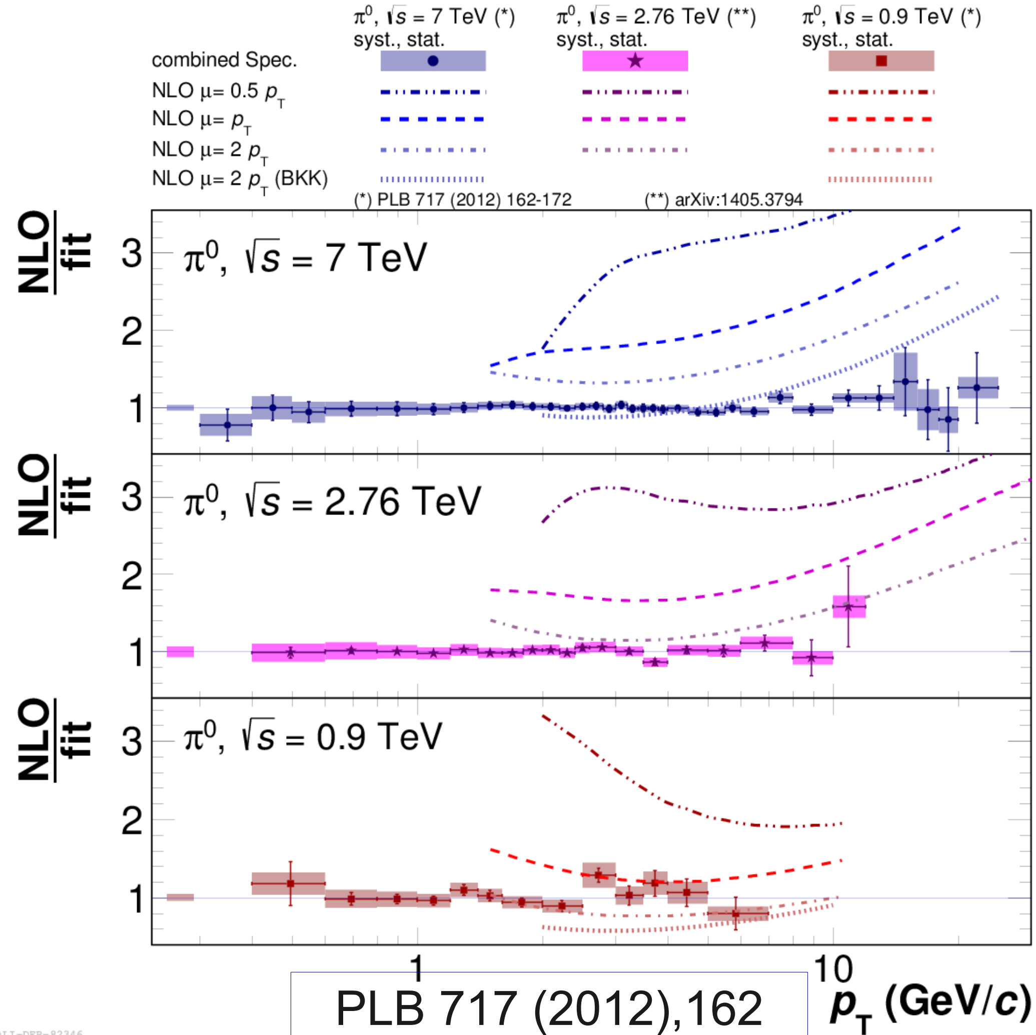






π^0 in pp at $\sqrt{s}$=0.9, 2.76, 7 TeV vs pQCD

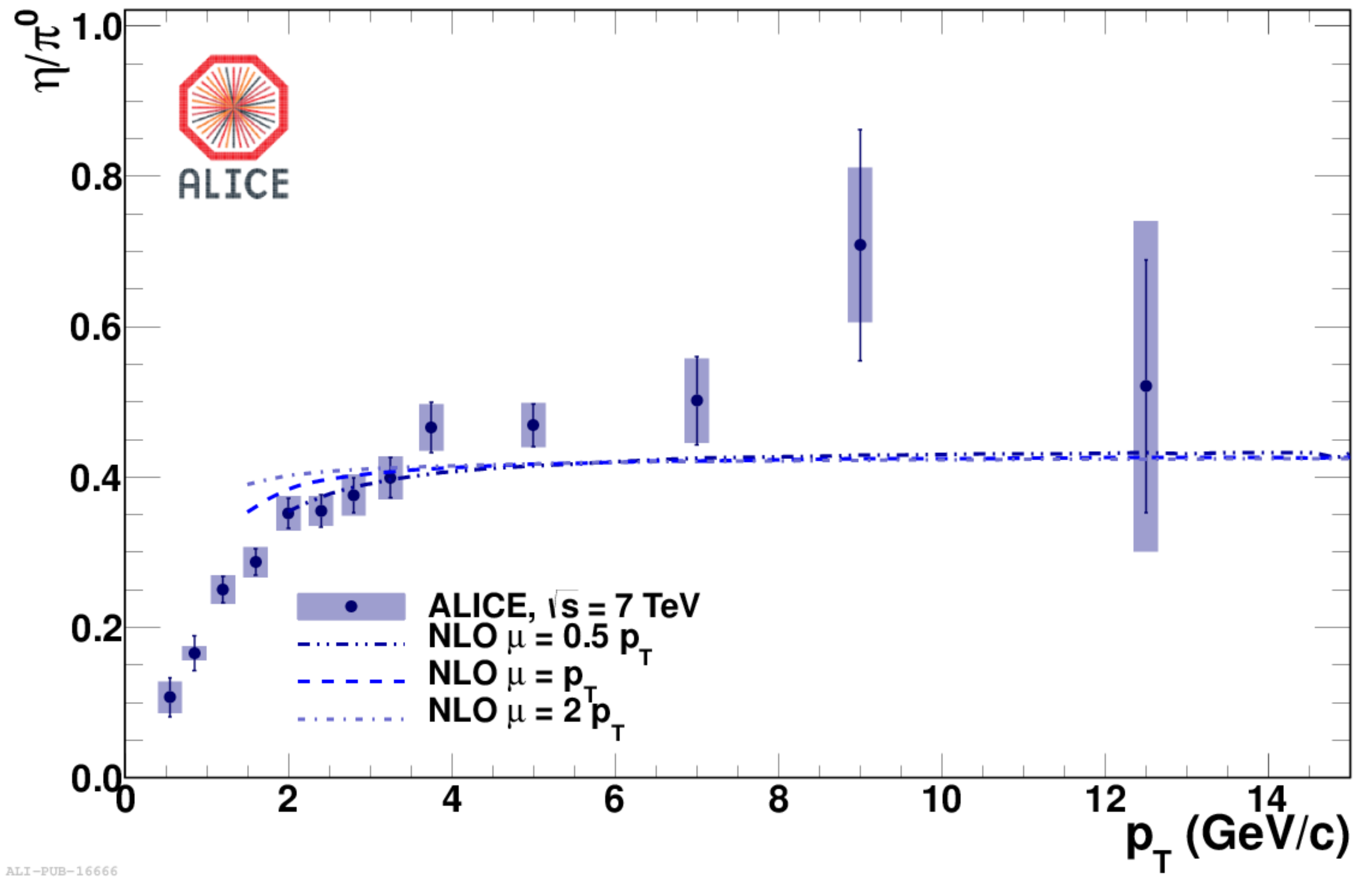




PLB 717 (2012),162
EPJ C74 (2014)3108

- pQCD NLO overestimates π^0 production at higher energies
- Gluon fragmentation can be dominant in hadron production at LHC energies, though gluon fragmentation is not known precisely

η/π^0 ratio in pp at $\sqrt{s}$=7 TeV

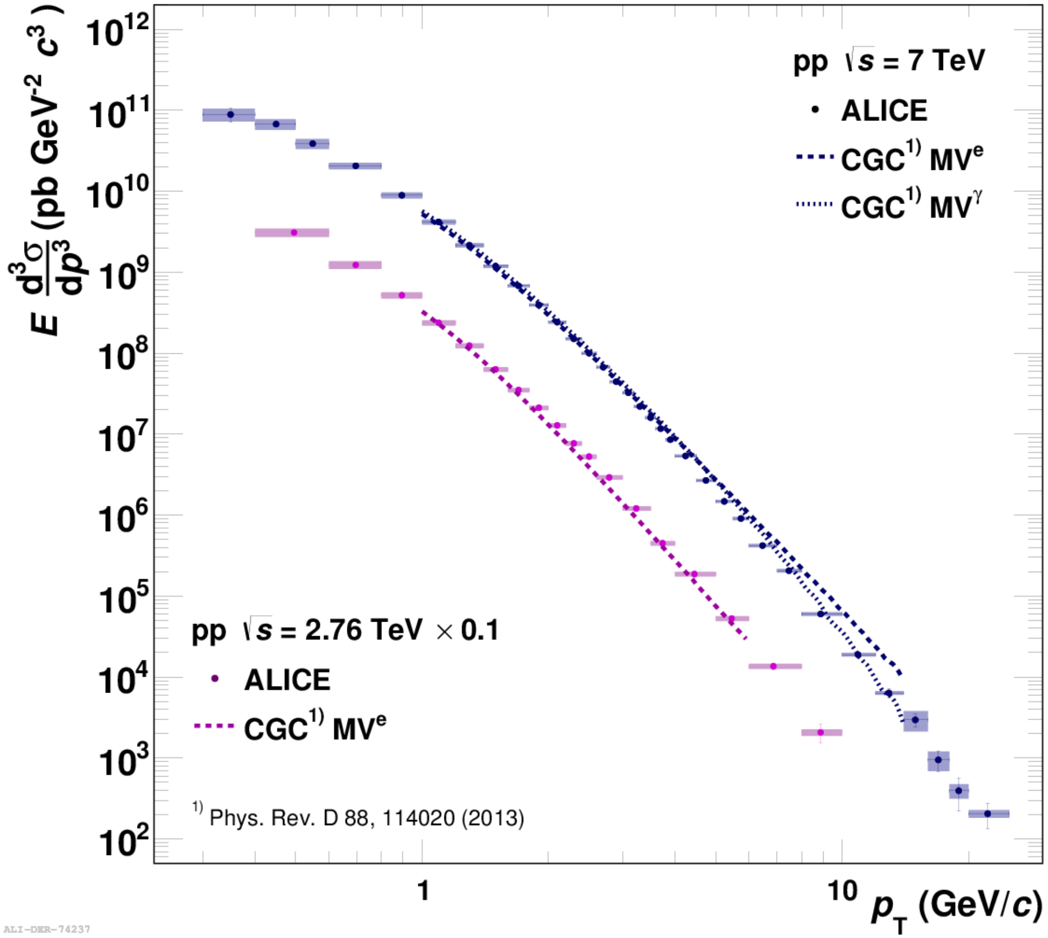


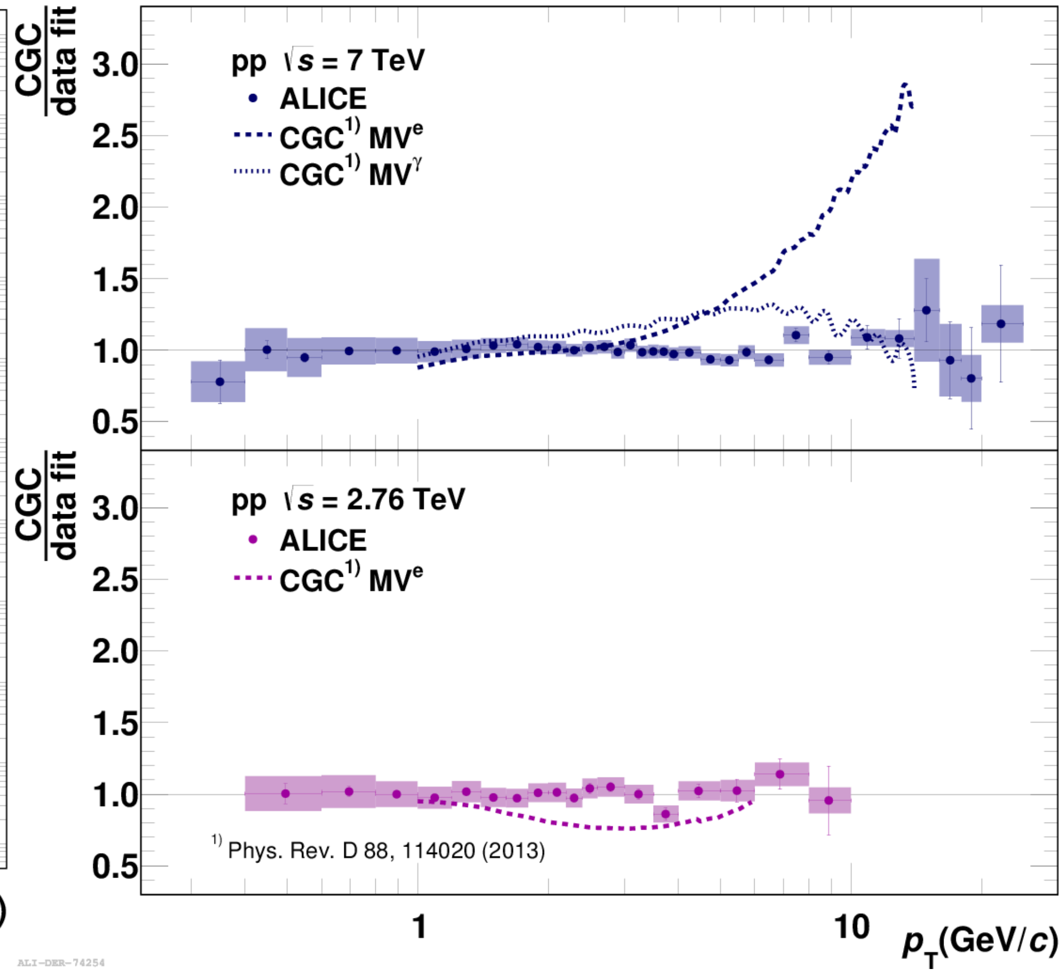
In spite of inability to describe π^0 and η spectra, pQCD NLO describes their ratio, though data at high p_T still have large uncertainties for model discrimination

pQCD NLO calculations by W.Vogelsang:

- η: PDF CTEQ6M5, FF AES
- π^0:PDF CTEQ6M5, FF DSS

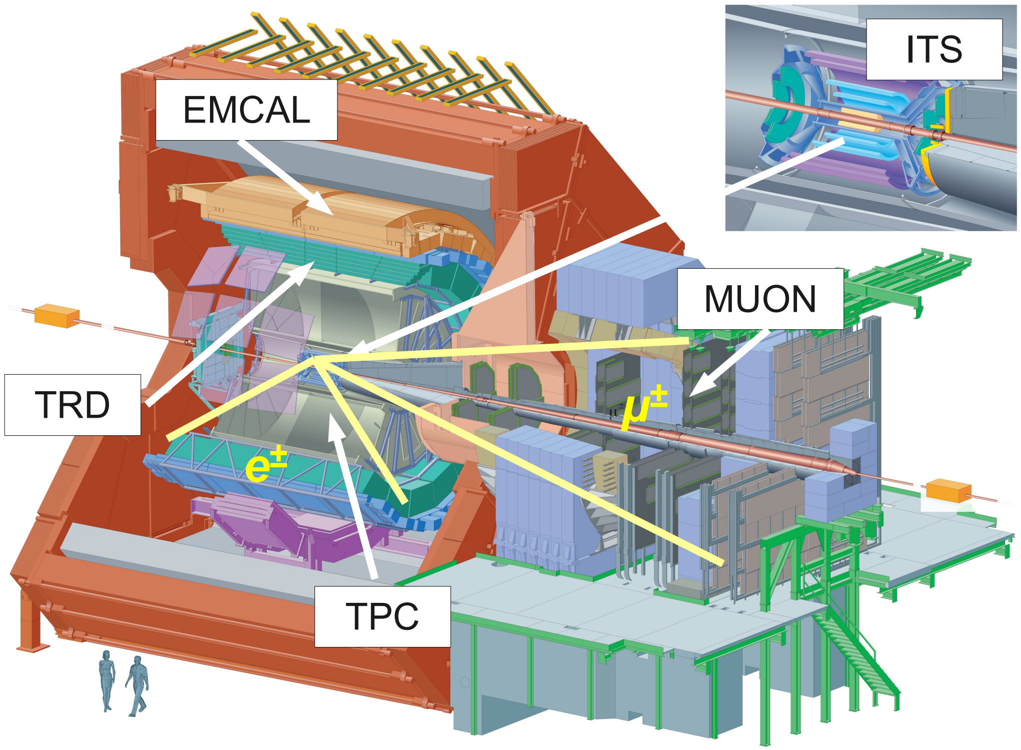
π^0 in pp at $\sqrt{s}$=7 TeV vs CGC





- CGC calculation for π^0 production: T. Lappi, H.Mäntysaari, Phys. Rev. D88 (2013) 114020
- Data described up to moderate/high p_T, no additional K factors!

Heavy flavour detection via leptons



Leptons are possible trigger particles

- BR 10% for $c, b \rightarrow l + X$
- Clean signature in calorimeters for high-momentum electrons
- At high p_T, muon sample has low background from hadronic decays

Muons

- $-4 < \eta < -2.5$ in MUON detector
- $p > 4$ GeV/c
- Background: π and K decays

Electrons

- $|\eta| < 0.9$, $p_T > 50$ MeV/c
- Tracking, vertexing and PID with ITS, TPC, TRD, EMCAL
- Background: from photon conversion, hadronic decays to e^+e^-

More heavy flavour studies in ALICE not covered by this talk:

- *D* meson reconstruction via their hadronic decays at mid-rapidity [PLB 718 (2012), 279; JHEP 1207 (2012) 191, JHEP 01 (2012) 128]
- Non-prompt J/ψ, reconstructing the $J/\psi \rightarrow e^+e$ at mid-rapidity [JHEP 11 (2012) 065]

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Why heavy flavours?

In proton-proton collisions:

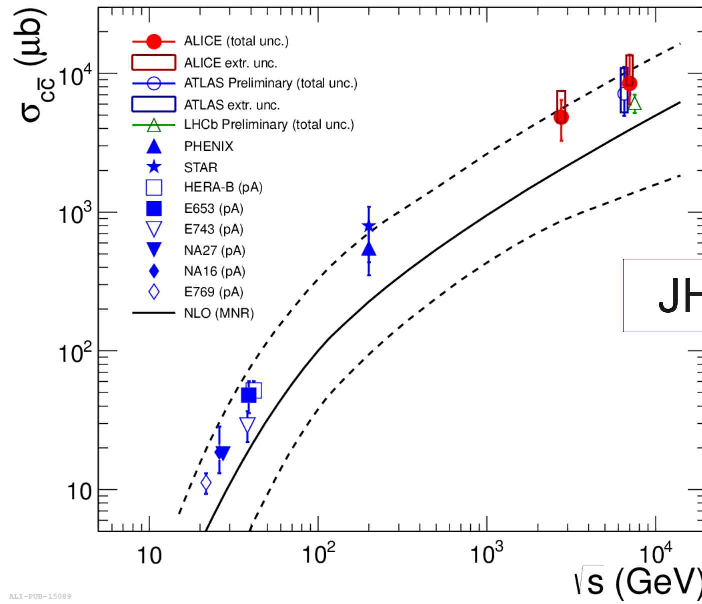
- charm and beauty quarks are produced in high-Q^2 partonic scattering processes
- higher cross section at the LHC

$$\sigma_{c\bar{c}}(LHC) \approx 10\,\sigma_{c\bar{c}}(RHIC)$$
$$\sigma_{b\bar{b}}(LHC) \approx 50\,\sigma_{b\bar{b}}(RHIC)$$

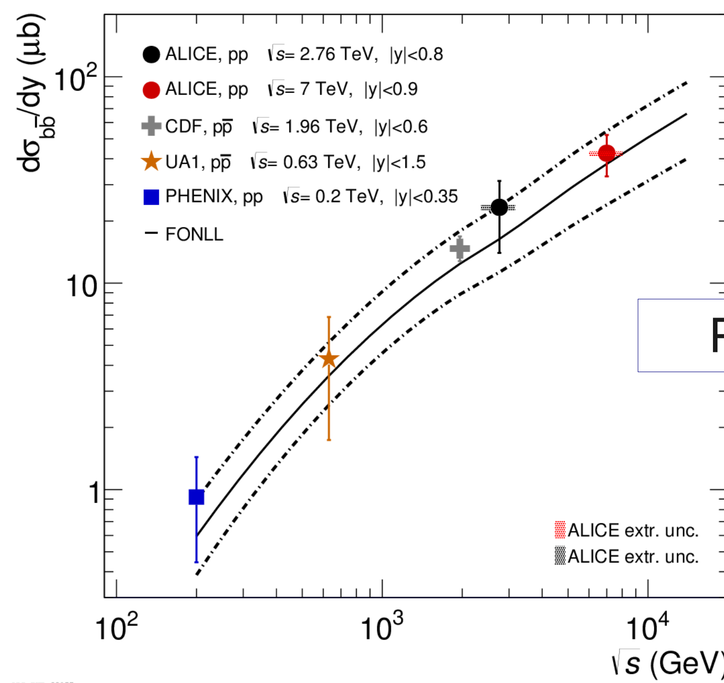
- test bench for pQCD calculations down to low p_T
- reference for heavy-ion data

In heavy-ion collisions:

- Heavy quarks are produced in the early stage of collisions
- Exposed to medium evolution
- No additional production in hadronic phase



JHEP, 2012, 2012:191



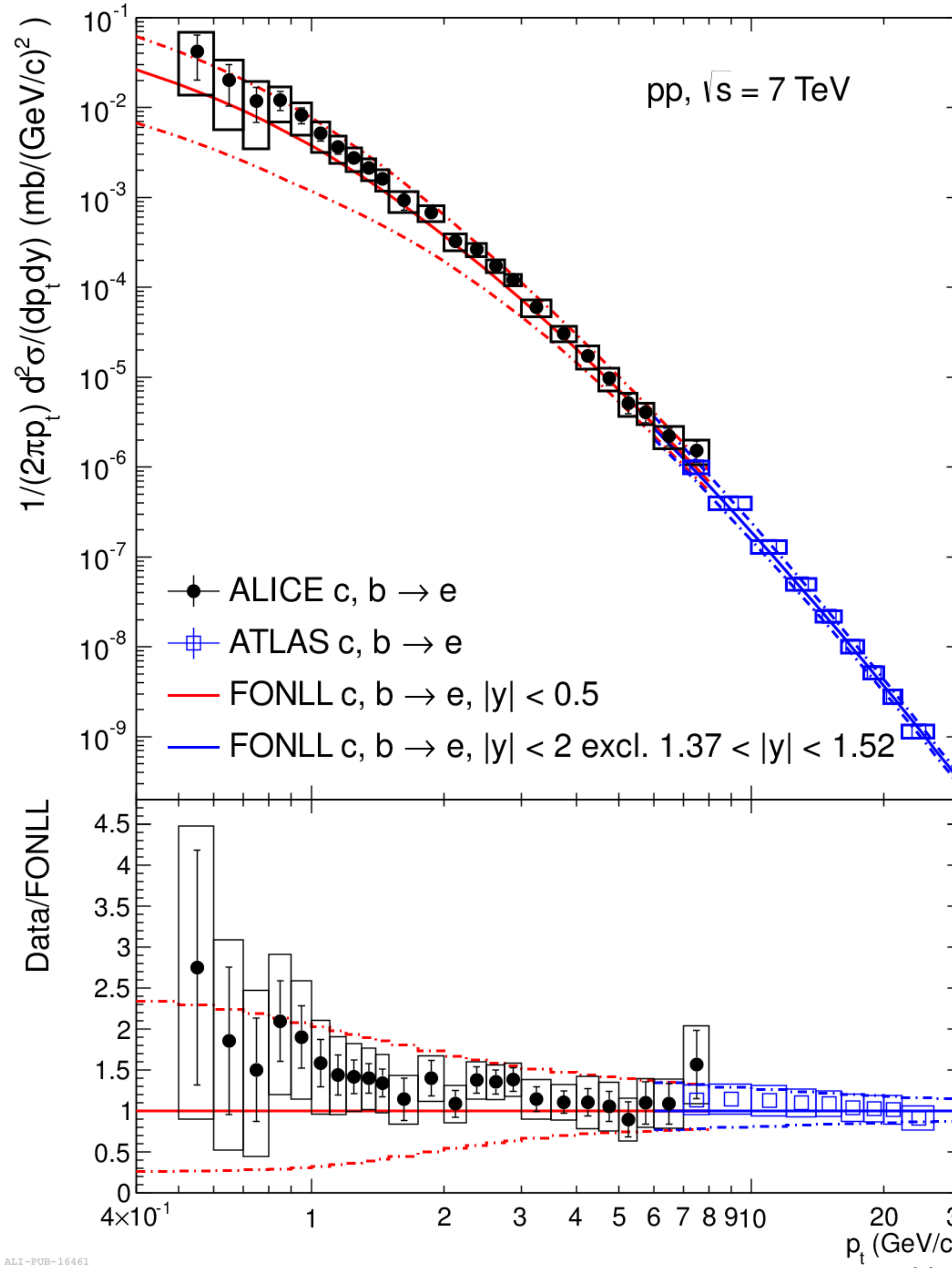
PLB 721 (2013) 13

pp at √s=7 TeV: *e* from heavy-flavour decays

Combined two electron identification methods:
- TPC+TRD+TOF
- TPC+EMCal

FONLL calculations describe the data within uncertainties over the full p_T range (Cacciari et al., arXiv:1205.6344)

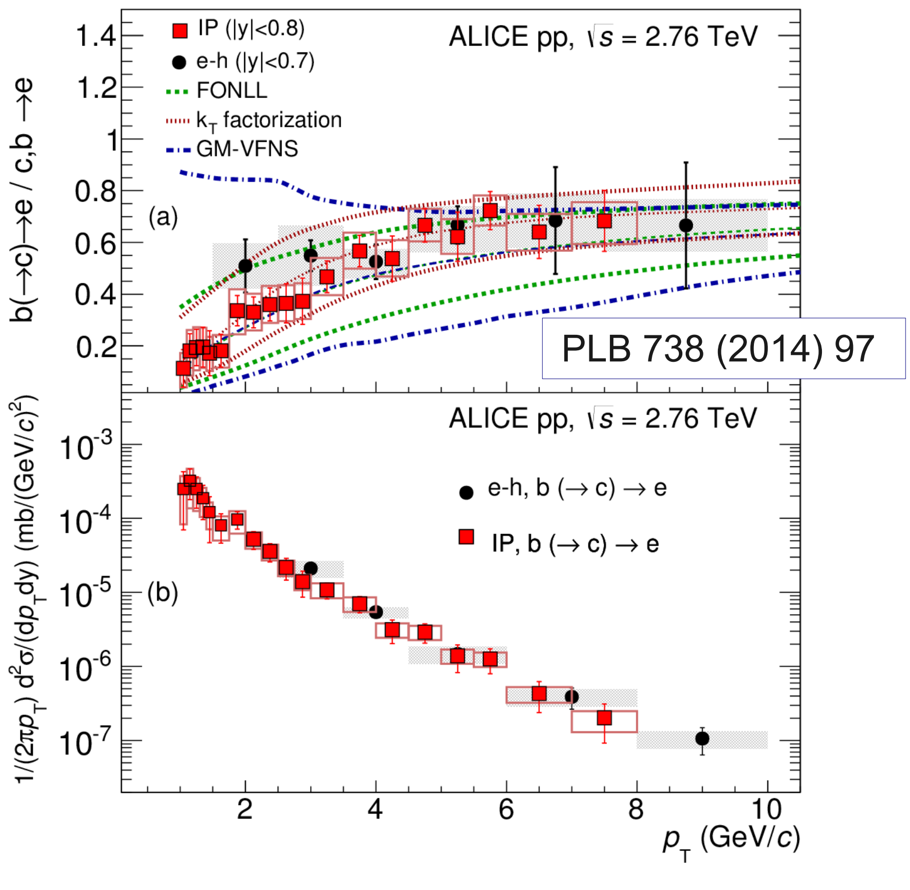
Complementary with ATLAS measurement together cover wide p_T range



ALICE, Phys. Rev. D 86, 112007 (2012)
ATLAS, PLB 707 (2012) 438

pp at √s=7 and 2.76 TeV: *e* from beauty decays

- Electrons from beauty reconstruction is based on
  - Displaced decay vertex (for beauty hadrons: cτ~500 μm)
  - Electron-hadron angular correlations
- FONLL pQCD predictions agree within uncertainties both with *c* and *b* differential cross section (FONLL: JHEP 1210 (2012) 37, GM-VFNS: EPJ C72 (2012) 2082, k_T-factorization : PRD 87 (2013) 094022



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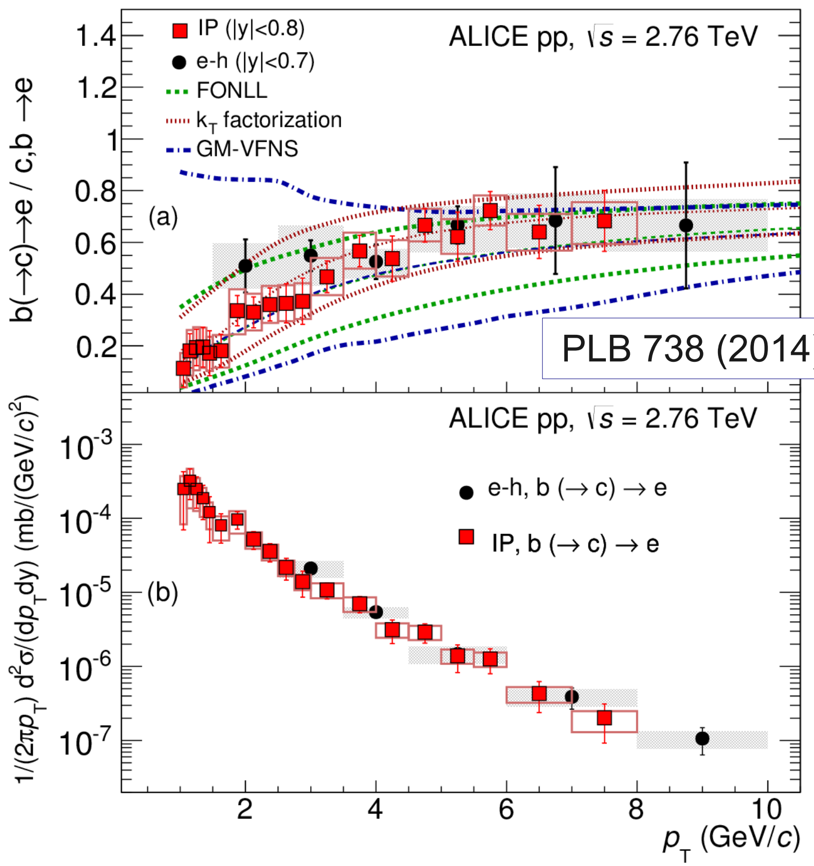
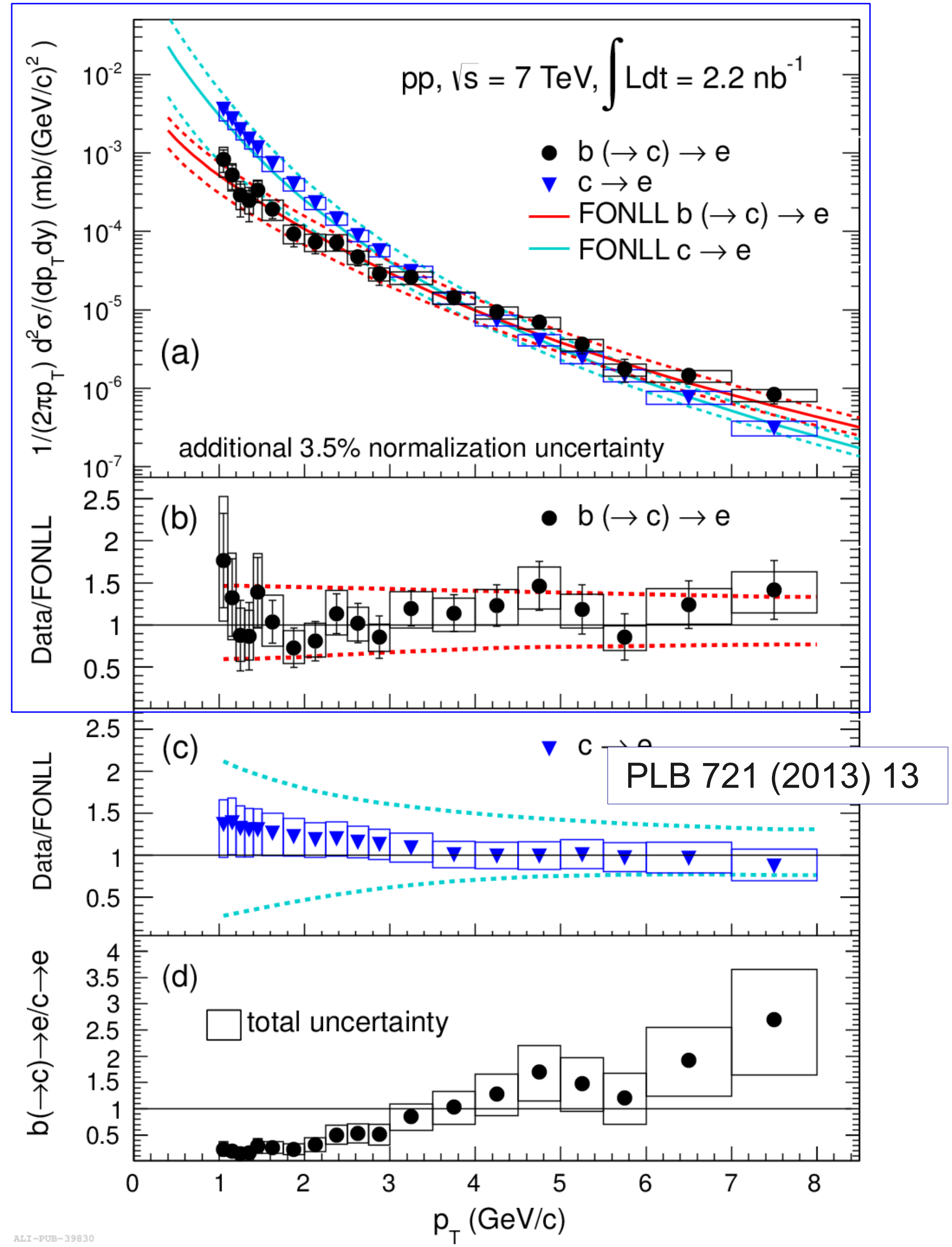
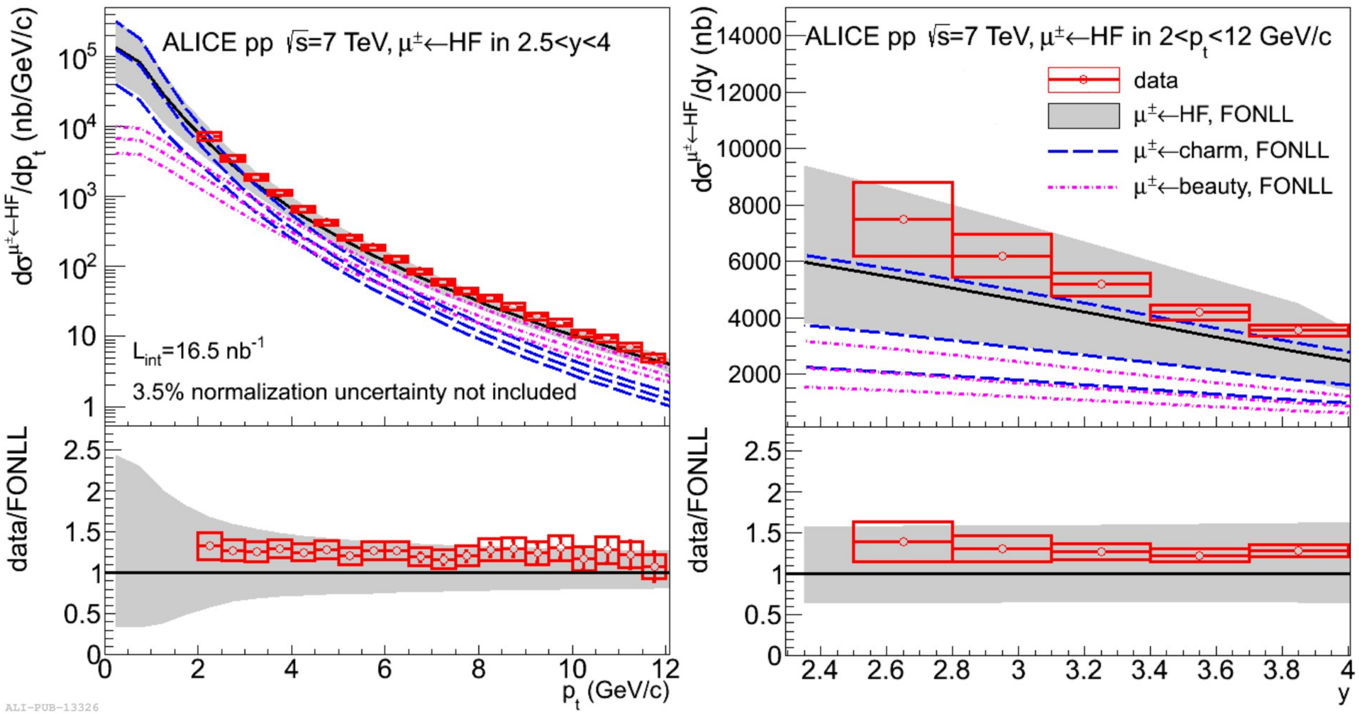


PLB 738 (2014) 97

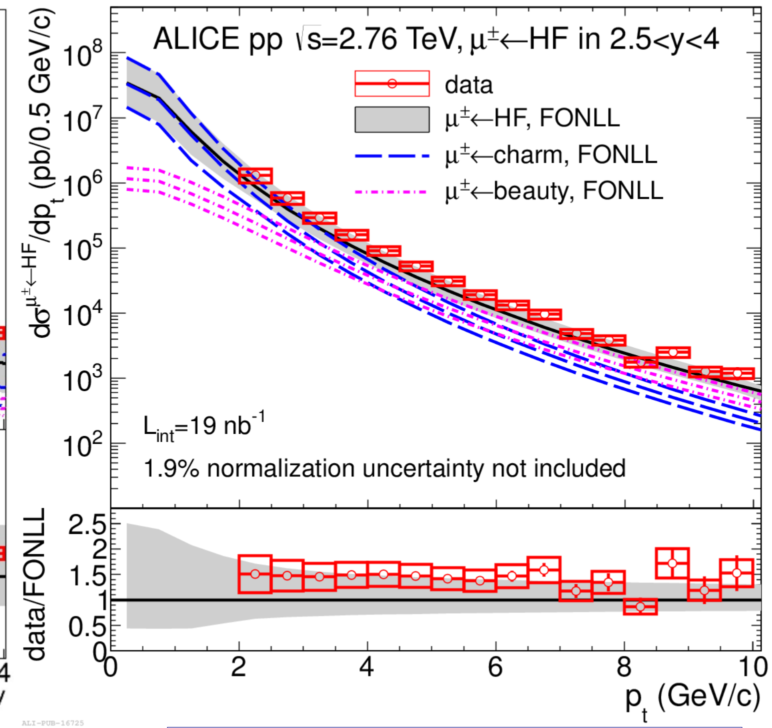


PLB 721 (2013) 13

pp at √s=7 and 2.76 TeV: μ from heavy flavour decays



PLB 708 (2012) 265

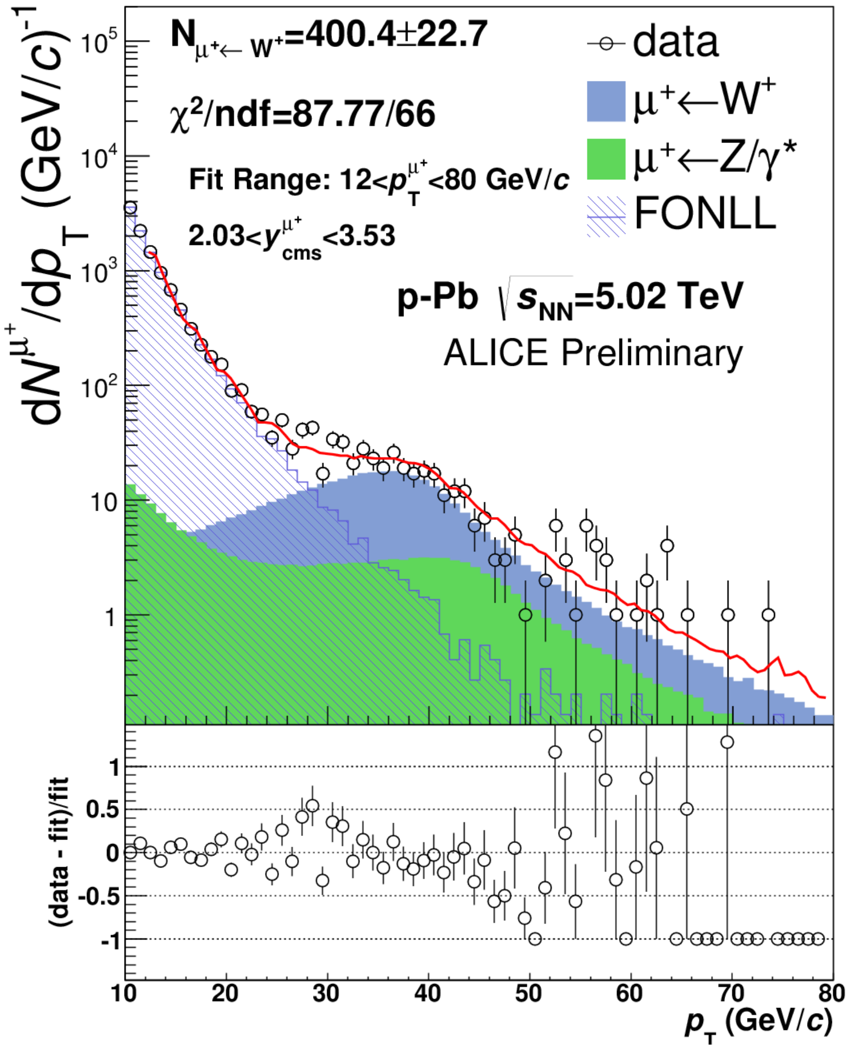


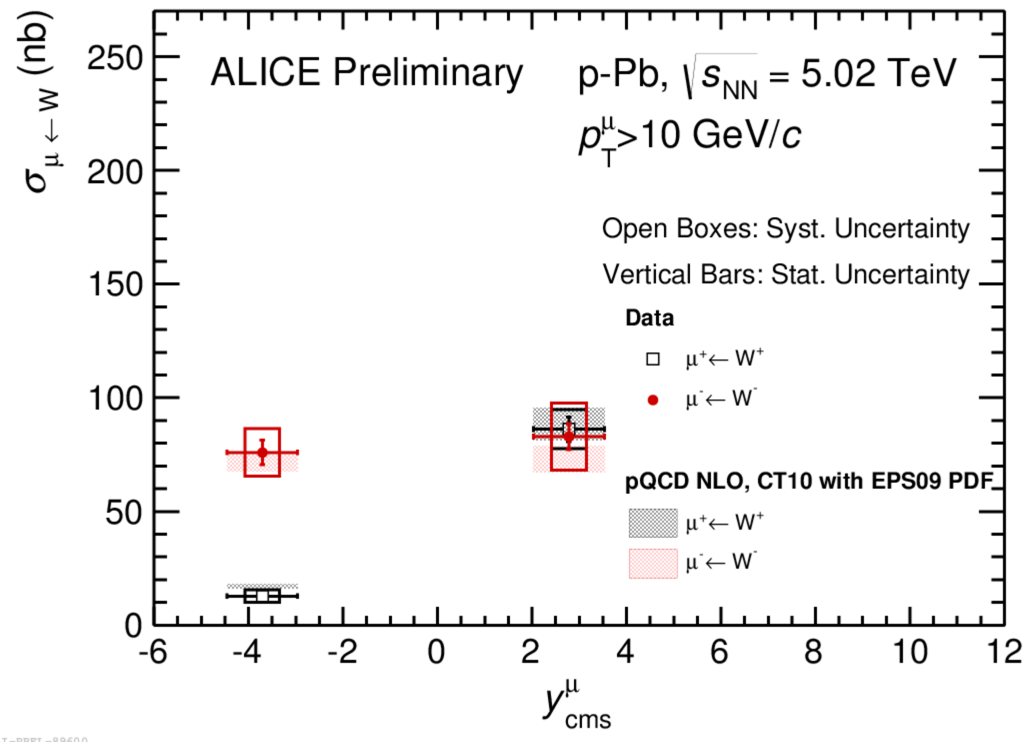
PRL 109 (2012) 112301

Muons from HF decays

- $-4<y<-2.5$
- background ($\mu\leftarrow\pi$, K) subtracted via MC simulation normalised to data at low p_T
- pQCD calculations describe both the p_T and y distributions within the uncertainties at both energies

p-Pb: muons from W decay





- μ p_T spectra: templates for $\mu \leftarrow W$ and $\mu \leftarrow Z/\gamma$ from POWHEG.
- The $\mu \leftarrow$HF background from FONLL.

$\mu^{\pm} \leftarrow W^{\pm}$ cross sections measured both at backward and forward rapidities

- Isospin effect visible at backward rapidity
- NLO pQCD calculation using CT10 + EPS09 PDF set reproduce the measurements within uncertainties [JHEP 1103 (2011) 071]

Summary and perspectives

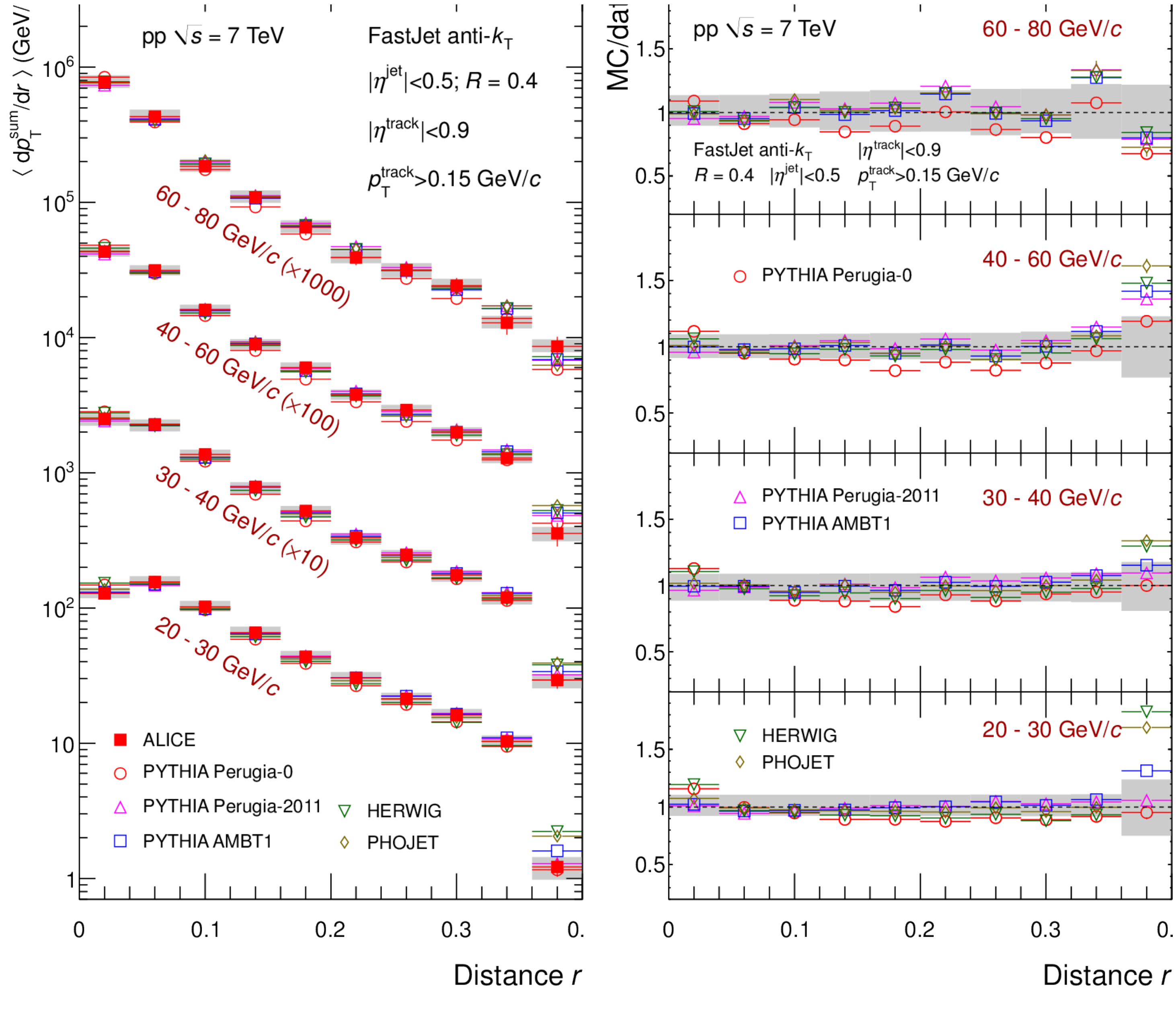
- This short talk could present only some highlights on ALICE QCD and SM measurements.
- Results show that new energy regime achieved at LHC requires updates in pQCD for light flavours.
- Heavy flavours and electroweak sector results are consistent with theory within (large) uncertainties
- During Run1, ALICE took data in pp at 4 collision energies: 0.9, 2.76, 7, 8 TeV. Run2 will bring data from 13 TeV.
- Enough to study spectra evolution with collision energy and scaling properties of hadron spectra
- Data from Run2 is expected to bring precise measurements of hadron production in pp collisions in a wide kinematic range

See more ALICE results at LHCP2015:

- E.Scapparone, *Selected QCD results with ALICE and LHCb*
- J.G.Contreras Nuno, *ALICE exclusive vector meson production*
- A.Ohlson, *Ridge in pA*
- E.Kryshen, *First look at 13 TeV*
- G.Bruno*, Hard probes in heavy ions*
- P.Antonioli*, Heavy flavour in pA and AA*

Backup slides

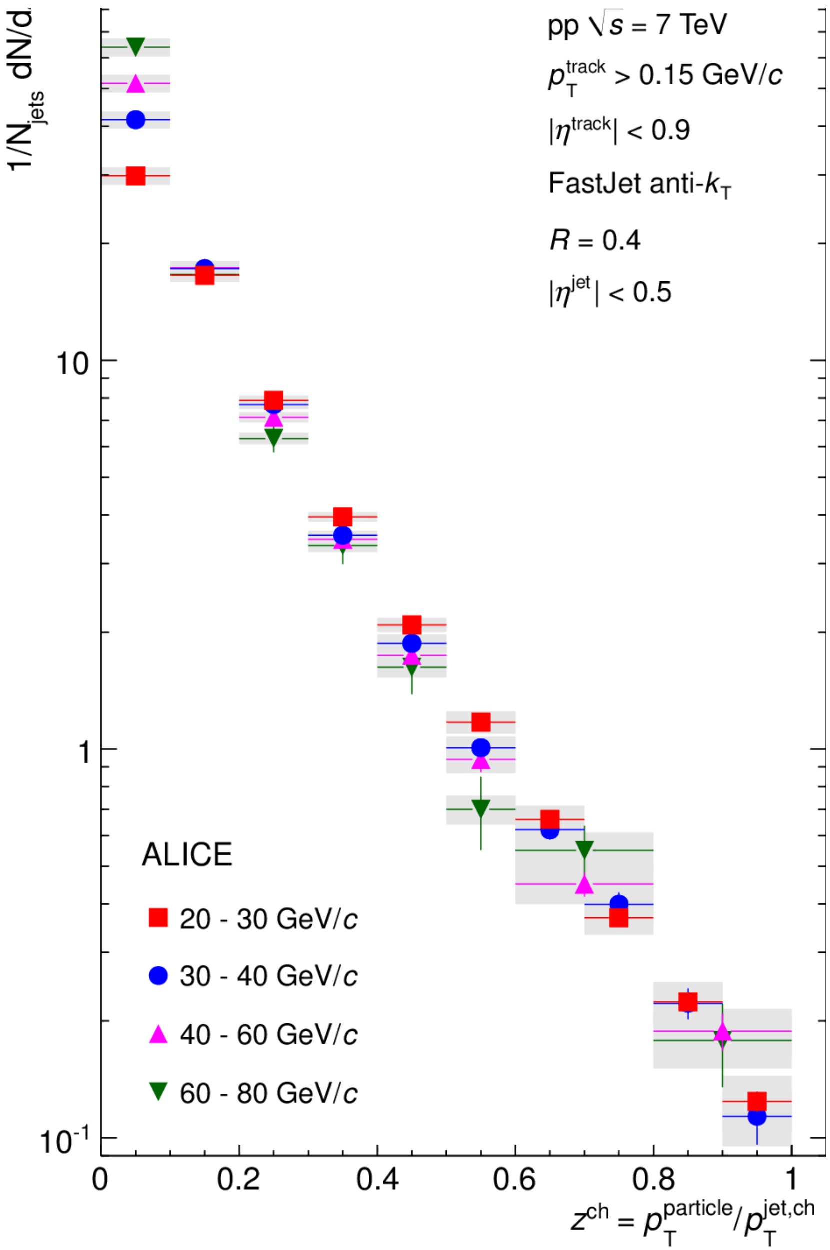
Radial p_T density in charged jet shape

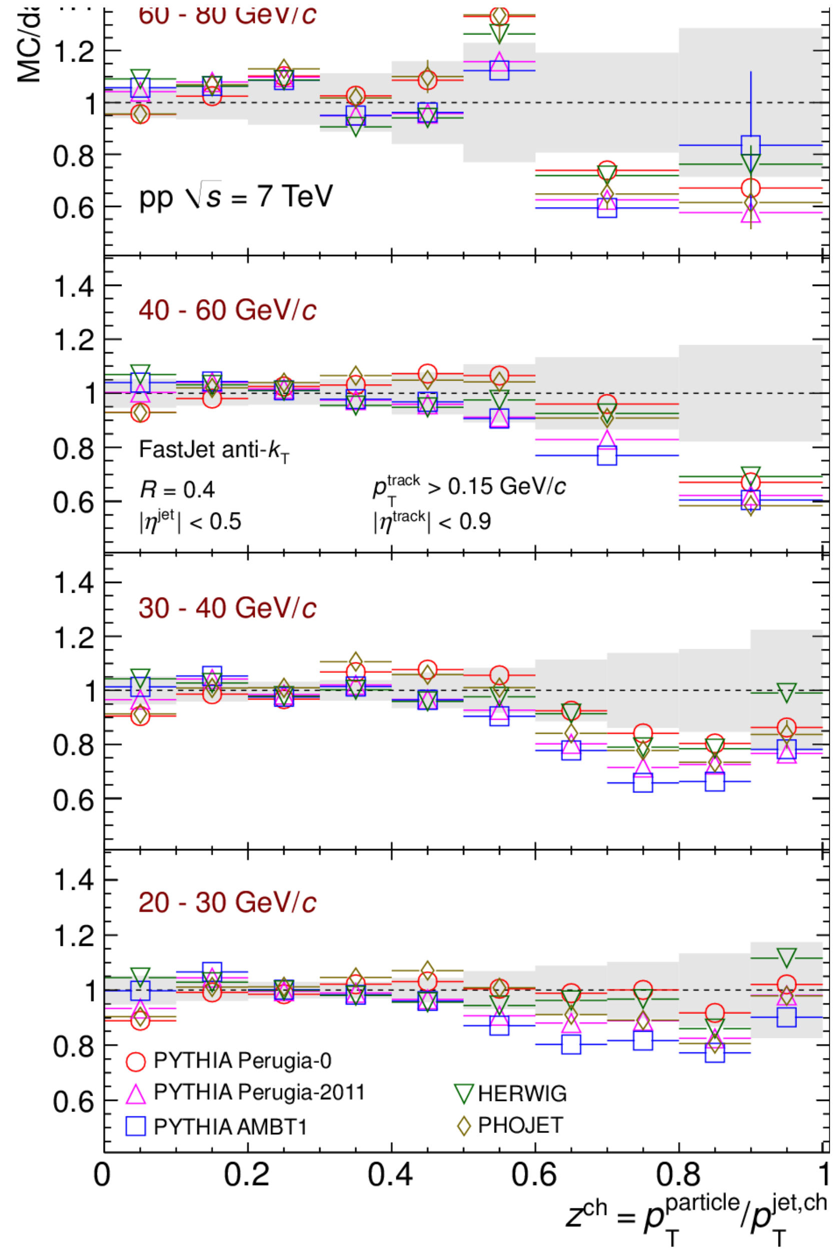


Radial distributions of p_T density as a function radial distance r from the jet direction for leading charged jets.

The measured radial density distributions distributions are well described by the PYTHIA model (tune Perugia-2011).

Fragmentation in charged jets



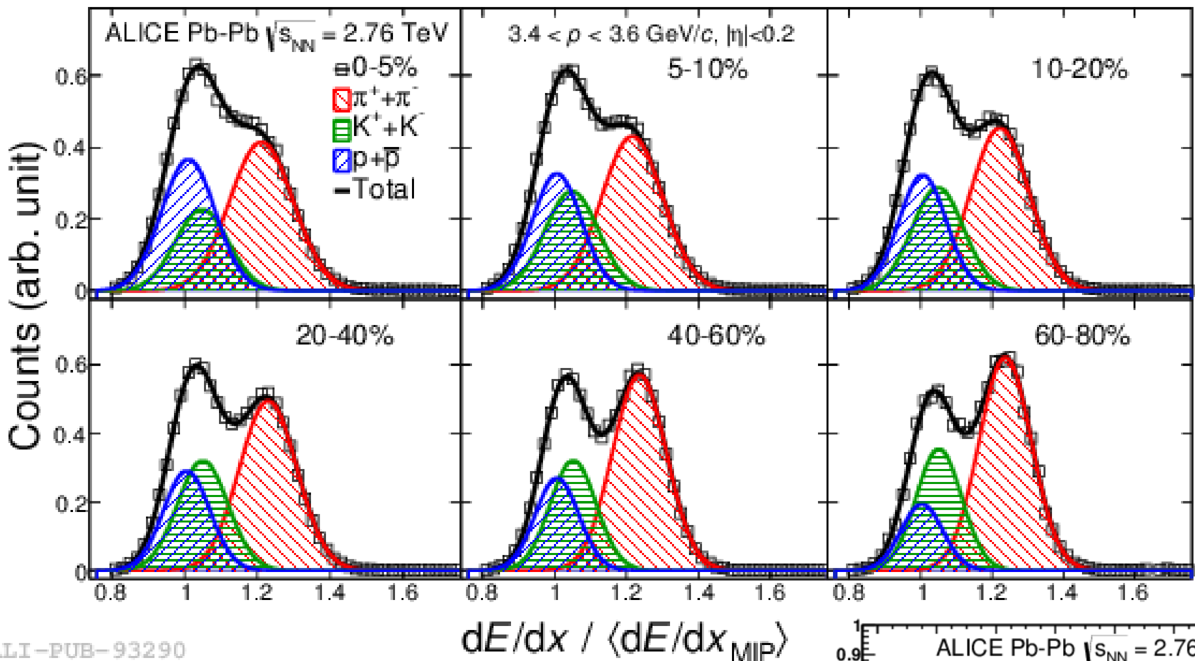


Fragmentation distributions F(z) are consistent for z^{ch} > 0.1 for all jet p_T.

Scaling of charged jet fragmentation with charged jet p_T.

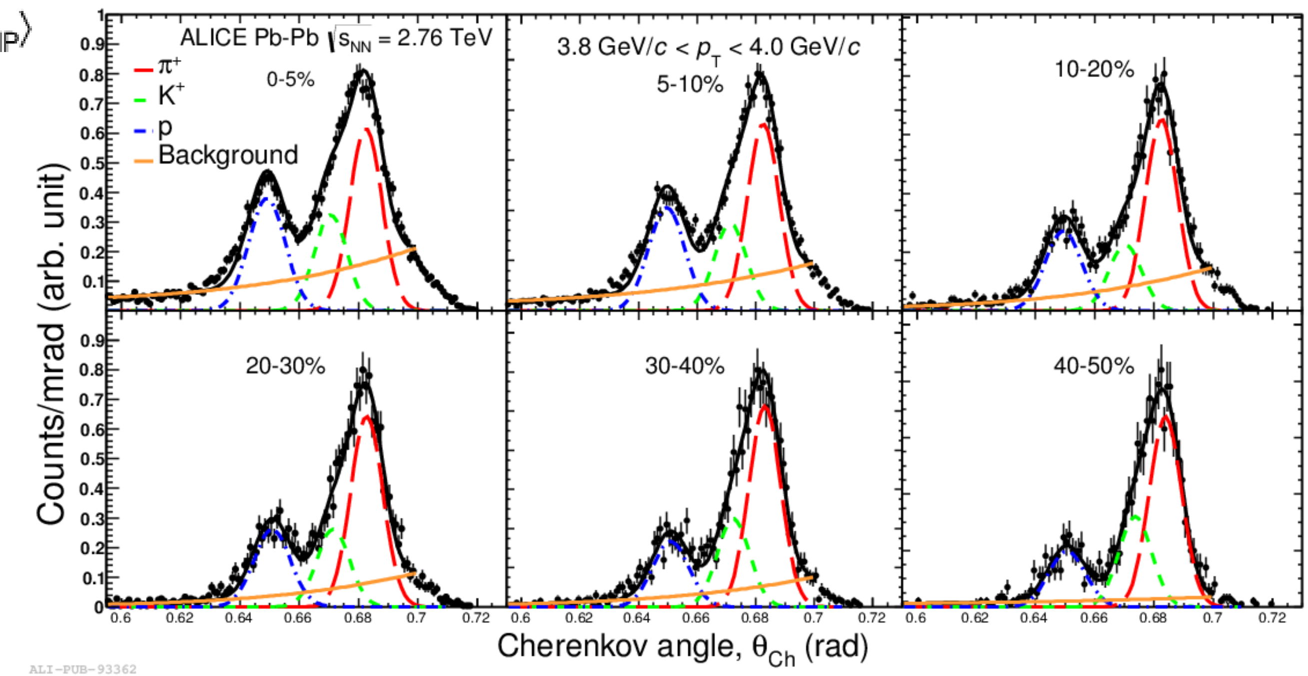
Jet fragmentation better described by HERWIG

Charged particle identification

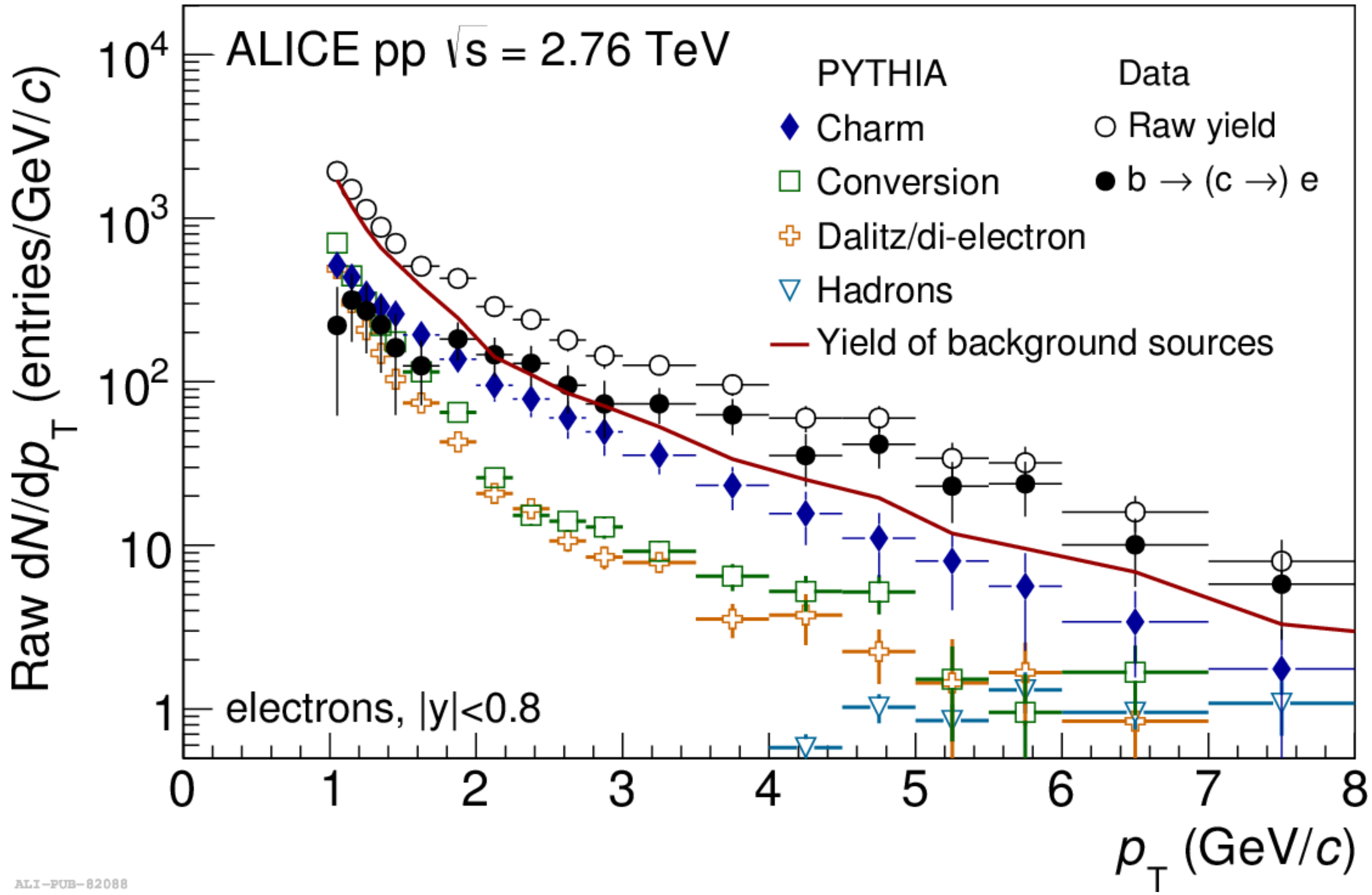


Four-Gaussian fits (line) to the dE/dx spectra for tracks at $3.4<p_T<3.6$ GeV/c

Distributions of the Cherenkov angle measured in the HMPID for tracks at $3.8<p_T<4.0$ GeV/c



Electrons from beauty



Raw spectrum of electrons compared to background sources (from charm hadron decays, photon conversions, Dalitz decays, and hadron contamination)